Latent Heat of Vaporization

Thermodynamics: phase change, latent heat of vaporization, boiling	

Qty	Equipment and Materials	Part Number
1	PASPORT Xplorer GLX	PS-2002
1	Fast-Response Temperature Probe (included with GLX)	
1	Basic Calorimetry Set (1 calorimeter cup, plastic tubing)	TD-8557
1	Steam Generator	TD-8556A
1	Large Base and Support Rod (optional)	ME-9355
1	Three-Finger Clamp (optional)	SE-9445
1	Balance	SE-8723
1	Glass tube, ¼" outside diameter, about 2" long	
1 L	Water, about 10 degrees *cooler* than room temperature	

Purpose

The purpose of this activity is to determine the amount of thermal energy contained in a specific quantity of steam (one gram) at a specific temperature (100º C). This amount of thermal energy is called the Latent Heat of Vaporization of water.

Background

When a substance warms or cools, thermal energy is transferred from or to the substance, and the substance changes temperature (up or down). The thermal energy, ΔQ, depends on the mass, m, the specific heat of the substance, c, and the temperature change, ΔT.

$$\Delta Q_{\text{temperature change}} = mc\Delta T$$

When a substance changes phase, the arrangement of its molecules changes, but its temperature does not change. If the new arrangement has a *higher* amount of thermal energy, the substance must *absorb* thermal energy *from* its environment in order to make the phase change. If the new arrangement has a *lower* amount of thermal energy, the substance must *release* thermal energy *to* its environment.

For example, the molecules in a gas have *more* kinetic energy, and the molecules in a liquid have *less* kinetic energy. The phase change from gas to liquid involves a transfer of thermal energy *out* of the substance, but doesn't involve a temperature change for the substance. The thermal energy, ΔQ, depends on the mass, m, and the latent heat of vaporization, H_v (the amount of energy per gram needed to change phase at a specific temperature).

$$\Delta Q_{\text{phase change}} = mH_v$$

If the substance changes from gas to liquid, and then the liquid undergoes a temperature change, the *total* amount of thermal energy involved is the sum of the thermal energy for the phase change and the thermal energy for the temperature change.

$$\Delta Q_{total} = \Delta Q_{\text{phase change}} + \Delta Q_{\text{temperature change}} = mH_v + mc\Delta T$$

The thermal energy comes from the environment that surrounds the substance.

Preview

Use a Fast-Response Temperature Probe to measure the change in temperature of a known mass of water as steam changes from gas to liquid in the water. Use the Xplorer GLX to record and display the temperature. Determine the latent heat of vaporization of the steam.

Safety Precaution

- Follow all directions for using the equipment. Be *very careful* around the Steam Generator.
- Wear protective gear (such as gloves, goggles, and lab coat.)

Procedure

GLX Setup

1. Plug a Fast-Response Temperature Probe into the first temperature port on the left side of the Xplorer GLX and then turn on the GLX (⏻).

- The Graph shows Temperature (ºC) and Time (s).

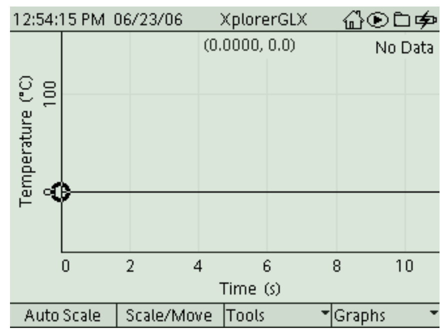

Fig. 1: GLX graph

Equipment Setup

1. Set up a PASCO Steam Generator with a water trap and plastic tubing as shown. Put a glass tube in the end of the piece of plastic tubing that will go into the calorimeter.
2. Fill the generator about two-thirds full of water and turn on the generator to "HIGH". Adjust the height of the water trap if necessary.

- NOTE: It is very important to have the bottom of the water trap above the level of water in the Steam Generator.

3. Measure and record the mass of a calorimeter from the PASCO Basic Calorimetry Set.
4. Fill the calorimeter approximately half-full of cool water (about 10º C below room temperature).
5. Measure and record the mass of the calorimeter plus water.

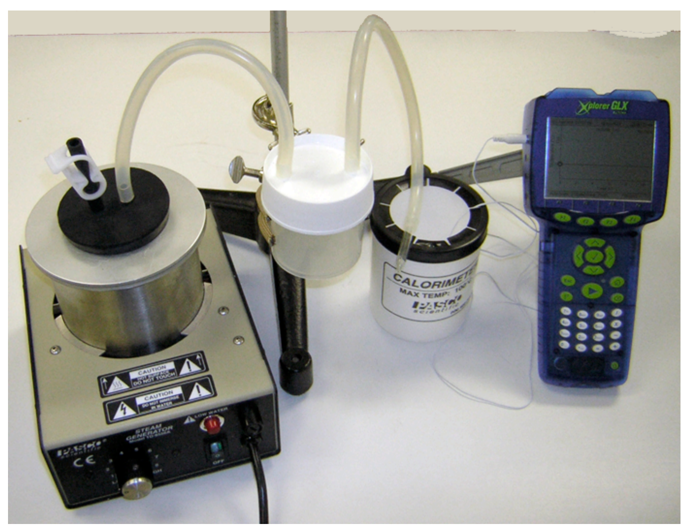

Fig. 2: Equipment setup

6. Wait until the steam flows freely for at least a minute, and then get ready to start recording data. BE EXTREMELY CAREFUL! True steam is invisible, and very, very hot!

Record Data

1. Press Start (▶) on the GLX to measure the signal from the Temperature Probe.

- The temperature appears in the graph display. Make a note of the initial temperature of the water.

2. Immerse the end of the tube from the steam generator into the cool water in the calorimeter. Gently swirl the water in the calorimeter.
3. Carefully watch the temperature in the Graph screen. When the water temperature gets as far *above* room temperature as it was initially *below* room temperature, remove the steam tube from the water and turn off the generator.
4. Continue to record data and to swirl the water until the water temperature reaches its highest value and begins to drop.
5. Press ▶ to stop data recording.
6. Remove the Temperature Probe and then immediately measure and record the mass of the calorimeter plus water plus condensed steam.
7. Clean up the equipment as instructed.

Analysis

1. Use the graph of temperature versus time to find the initial temperature of the water and the equilibrium temperature, or final temperature, of the water and the condensed steam.
2. Press F3 (F3) to open the 'Tools' menu. Select 'Smart Tool'. Use the arrow keys to move the cursor to the part of the graph that shows the initial temperature of the water. Record the value.
3. Repeat the process to find the final temperature (equilibrium temperature) of the water and the condensed steam.
4. Use your measurements of the mass of the calorimeter, the calorimeter plus water, and the calorimeter plus water plus steam to determine the mass of the water and the mass of the condensed steam.
5. Use the mass of the water, the mass of the steam, and the initial and final temperatures of the water to calculate the heat of vaporization of water.

The steam starts at 100º C, condenses, and then cools down to the same final temperature as the water. The thermal energy transferred *from* the steam as it changed to water and then cooled down is the same as the thermal energy transferred *to* the water as it warmed up from its initial cool temperature to the final temperature.

In other words, the sum of the latent heat of vaporization, $\Delta Q_{phase\ change}$ plus the thermal energy for changing the temperature of the condensed steam, $\Delta Q_{temperature\ change}$, is the same as the thermal energy for changing the temperature of the water.

$$\left(\Delta Q_{phase\ change} + \Delta Q_{temperature\ change}\right)_{steam} = \Delta Q_{water}$$

$$m_{steam}H_v + m_{steam}c_{water}\Delta T_{steam} = m_{water}c_{water}\Delta T_{water}$$

$$m_{steam}H_v + m_{steam}\left(4186 J / kg^\circ C\right)\left(T_{final} - 100^\circ C\right) = m_{water}\left(4186 J / kg^\circ C\right)\left(T_{final} - T_{inital}\right)$$

The first task is to solve for H_v, the latent heat of vaporization. Then, substitute values for the mass of the steam, the mass of the water, the initial temperature of the water, and the final temperature of the water.

Record your results and answer the questions in the Lab Report.

Lab Report - Activity 32: Latent Heat of Vaporization

Name ________________________________ Date ___________

Data

Sketch your graph of temperature versus time. Include labels and units on the axes.

Data Table

Item	Value
Mass of calorimeter	kg
Mass of calorimeter **plus** water	kg
Mass of water, m_{water}	kg
Mass of calorimeter **plus** water **plus** condensed steam	kg
Mass of steam, m_{steam}	kg
Initial Temperature of Water, $T_{initial}$	ºC
Final Temperature of Water, T_{final}	ºC

Calculations

Calculate the mass of the water, m_{water}. Calculate the mass of the steam, m_{steam}.

Use the mass of the water, mass of the steam, specific heat of water (c_{water} is 4186 J/kg˚C), initial temperature of the water, and final temperature of the water to calculate the latent heat of vaporization.

$$\left(\Delta Q_{phase\ change} + \Delta Q_{temperature\ change}\right)_{steam} = \Delta Q_{water}$$

$$m_{steam}H_v + m_{steam}c_{water}\Delta T_{steam} = m_{water}c_{water}\Delta T_{water}$$

$$m_{steam}H_v + m_{steam}\left(4186J / kg°C\right)\left(T_{final} - 100°C\right) = m_{water}\left(4186J / kg°C\right)\left(T_{final} - T_{inital}\right)$$

First, solve the final equation for H_v, the latent heat of vaporization. Next, substitute your values for mass of water, m_{water}, mass of steam, m_{steam}, initial temperature, $T_{initial}$, and final temperature, T_{final}. Finally, calculate the results. The units for the latent heat of vaporization are joules per kilogram, or J/kg.

Get the accepted value for the latent heat of vaporization for water from your instructor, and calculate the percent difference between your value and the accepted value.

Item	Value
Latent Heat of Vaporization, measured	kJ/kg
Latent Heat of Vaporization, accepted	kJ/kg
Percent difference	%

$$\%diff = \left|\frac{measured - accepted}{accepted}\right| \times 100\%$$

Questions

1. How does your measured value for the latent heat of vaporization compare to the accepted value?

2. What factors do you think may have caused a difference, if any?

3. Why would a burn produced by 1 gram of steam at 100 ºC do more damage to your skin than a burn caused by I gram of hot water at 100 ªC?